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Developing an iBeacon-based Ubiquitous Learning Environment in Smart Green Building Courses*

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Based on the Science Technology and Society (STS) teaching framework, a ubiquitous situated learning system was developed in this study using emerging man-machine interaction technologies, such as iBeacon and Quick Response codes (QR code), to teach the science, technology and society aspects of smart green buildings. After the teaching experiment, statistical analyses were conducted to explore the connections among the subjects' sex, prior knowledge levels, quiz scores, time spent in completing the quiz, confidence in their knowledge about smart green buildings, perceived usefulness of the system, and learning interest. The subjects in this study were 35 junior students of a department of architectural design at a university in Taiwan. Twenty-six of them were male and 9 female. According to the analysis of the results, the use of the system could help to significantly improve the students' learning results regardless of the differences in their prior knowledge levels. In addition, the interactive learning provided by the system was accepted by the students and it could help the students to effectively improve their test scores, knowledge confidence and learning interest.

Keywords: ubiquitous learning; iBeacon; science technology and society (STS); mobile learning; intelligent green building

1. Introduction

Smart buildings and green buildings are the two topics of great importance currently in architecture/engineering education [1]. Between them, green buildings are capable of saving energy, saving water, protecting the environment and helping people to ensure sustainable development [2] while smart buildings are green buildings with better performance enabled by using information and communication technology (ICT), Internet of things (IoT) and other advanced technologies [3]. Integrating the concepts of smart buildings and green buildings, smart green buildings cover a wide variety of fields such as architecture, energy management, safety monitoring, energy-saving household appliances, automatic control, air-conditioning energy conservation, indoor environment quality, water conservation, and lighting management. Therefore, in addition to equipping students with architecture-related knowledge, it is important for the traditional university education about architecture to teach students about emerging technologies used in smart green buildings as well.

In addition to the related technologies, the education about smart green buildings must also teach students to be aware of what people need from these technologies and what the technologies can bring to society. In the past, the teaching of science and technology tended to exclude the humanistic side of science of technology while teaching of humanities tended to lack a foundation supported by science and technology. To solve this knowledge gap, the Science-Technology-Society (STS) theory was proposed to provide a complete teaching framework with the focus on integrating science, technology and society [4]. According to the theory, science and technology education must be based on personal life experiences and social interactions. In other words, the concept of STS is to help students develop interactive logics among science, technology and society. By learning knowledge from all the perspectives of science, technology and society, students can learn in a way more relevant to the real life in society and develop required abilities of innovative thinking and problem solving [5].

The STS framework can be integrated with the current information technology and ubiquitous computing technology, through which the STS framework can be realized in a learning environment, enabling students to learn targeted knowledge on campus or in their daily-life environment. This kind of ubiquitous learning can also help students and teachers to have exchanges, sharing and interactions about different topics, and consequently help students to improve their learning results [6–7]. The so-called "ubiquitous learning"

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refers to the ability of learners to access the information they intend to learn anytime and anywhere. With the advancements of mobile communication technologies nowadays, mobile learning is one of the most convenient ways of learning.

To sum up, ubiquitous learning is based on the merge of domain knowledge and application context [7–9] and also on the effective integration of e-learning and mobile learning technologies/tools to form a ubiquitous learning environment [10]. Supplemented with courses or learning activities based on ubiquitous learning, traditional classroom-based learning can be more effective in improving learning performance and motivation [11–12]. According to education experts, knowledge construction should be implemented through learning activities in real-life situations [13–14]. In real-life situations, learnings can appreciate the meanings of the knowledge to learn, establish connections between the knowledge and its application, and consequently identify with the knowledge more easily [14–15] This kind of learning method is also called "situated learning". Using the technology of ubiquitous learning to realize situated learning is a major development direction for education of construction and engineering in vocational schools that focus on equipping students with practical knowledge and skills.

Based on the STS teaching framework, this study integrates traditional classroom-based education of the "science" and "technology" of smart green buildings with learning activities that focus on the "social" aspect of smart green buildings as sustainable, liveable and healthy living environments for people. In addition, ubiquitous learning is also used in this study to embed the knowledge about the science and technology of smart green buildings in the surroundings of the students and help them appreciate the connections among the science, technology and society aspects of smart green buildings. This study is intended to find out the students' acceptance of the interactive, ubiquitous situated learning system developed in this study and its influences on the students' learning achievements and motivation about smart green buildings in addition to their learning in the classroom. This study aims to answer the following two questions:

1. Can the ubiquitous situated learning system developed in this study improve learners' learning results and confidence?
2. Can the ubiquitous situated learning system developed in this study be accepted by students of construction/engineering education? Can it make the students feel interested in its learning activities?

2. Building a situated learning system about smart green building based on the STS framework

The ubiquitous situated learning system developed in this study is based on the STS framework, covering the three dimensions of science, technology and society. As illustrated in Fig. 1, the topic of smart green buildings cover the following aspects of science, technology and society: environmental science (such as environmental science and environmental chemistry), physics (such as dynamics, thermodynamics and material science), computer science (such as artificial intelligence and expert system), green building technology (such as room temperature control and ventilation control), smart control system (such as temperature detectors and moisture detectors), building energy efficiency system (such as renewable energy and power conservation), environmental protection (ecological conservation and species conservation), national development (competitive edge), and sustainable development (environment and species).

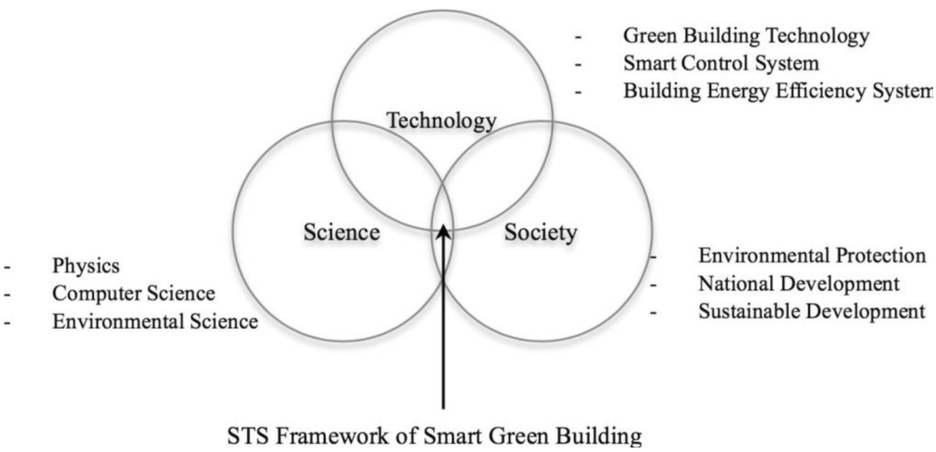

Fig. 1. Knowledge Related to Smart Green Buildings under the STS Framework.

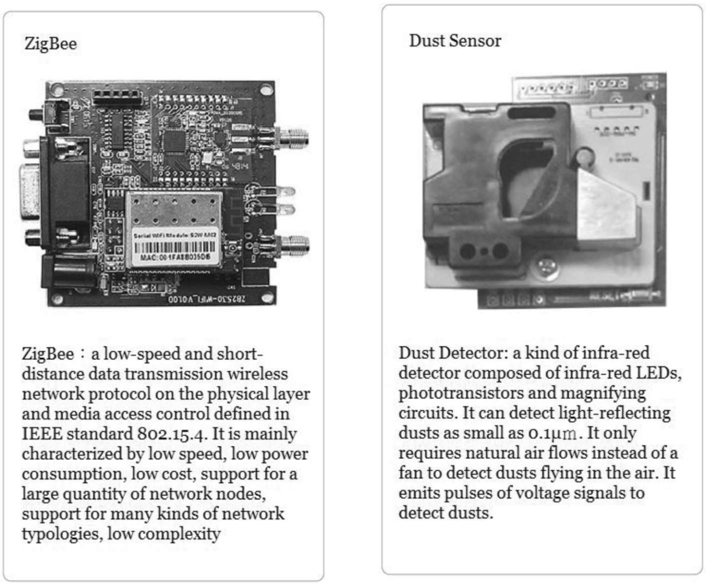

Fig. 2. Knowledge Card Examples of IoT and Smart Green Building Technologies (ZigBee and Dust Sensor).

To simplify the knowledge contents within the STS framework of this study, an architect, a man-machine interaction expert and an IoT engineer were consulted. Their professional knowledge of smart green buildings and IoT was collected and compiled to produce easy-to-understand knowledge cards about the science and technology of smart green buildings. Each knowledge card contains a title, description and photo of a science or technology of smart green buildings. In total 36 knowledge cards were completed and stored on the cloud. When a student holding a smart phone is approaching a device that uses a science/technology of smart green buildings inside the experiment laboratory of this study, the corresponding knowledge card will be transmitted to the student's phone so that he or she can have real-time access to the related knowledge. Two examples of the knowledge cards are provided as Fig. 2.

In the teaching of the science and technology of smart green buildings to the students, an experiment laboratory simulating the space inside a smart green building was established in this study (see Fig. 3). From its entrance to different areas in the lab, there

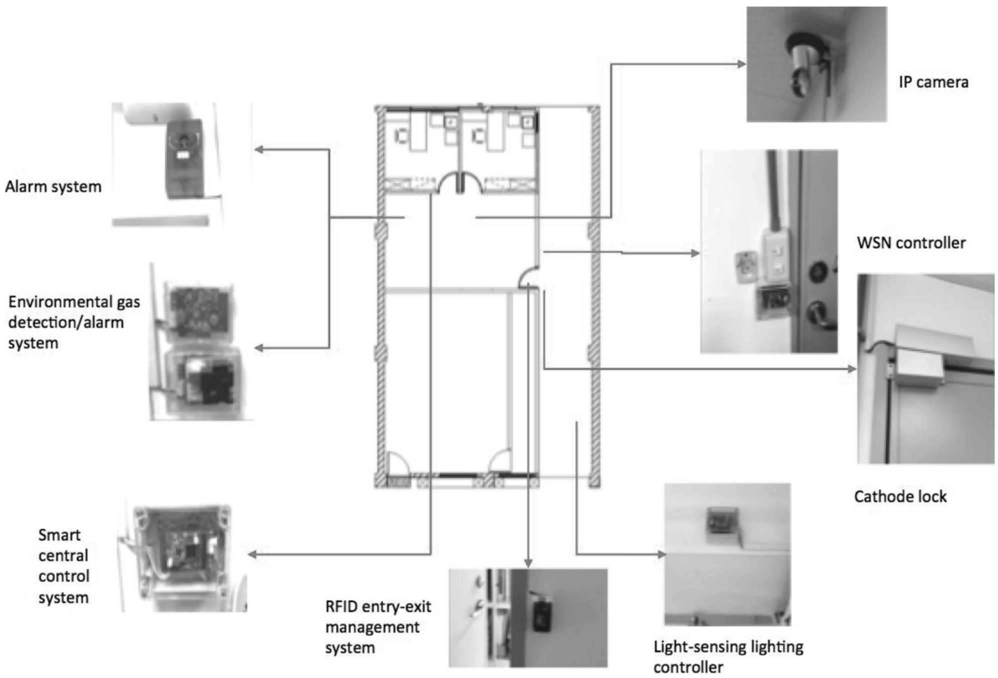

Fig. 3. Experiment Lab Simulating the Space inside a Smart Green Building.

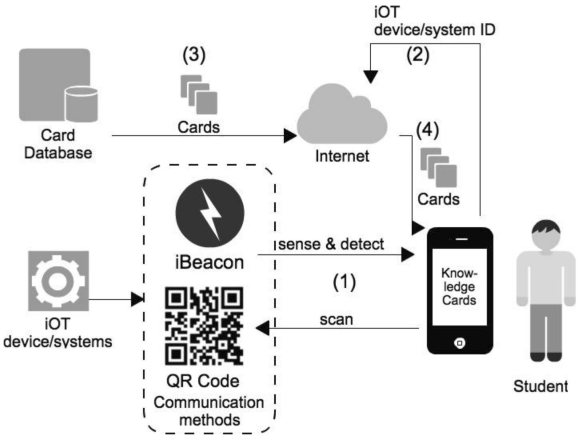

Fig. 4. Situated Learning Environment Supported by iBeacon.

Fig. 5. Display of the knowledge card on the phone.

were different functional modules/devices using different kinds of smart green building technologies for different purposes: smart central control system, IP camera, WSN controller, cathode lock, light-sensing lighting controller, RFID entry-exit management system, and environmental gas detection and alarm system.

This lab simulating the interior space of a smart green building could provide situated learning for students to learn about these related technologies and how they were applied in real-life situations. Under the STS framework, the students could learn and think about how to efficiently and effectively use the science and technology of smart green buildings to fulfill the requirements of people and society as a whole.

In this study, the iBeacon technology recently developed by Apple Inc. was also used to build the ubiquitous learning situation. iBeacon is a new technology of indoor positioning, using low-power Bluetooth 4.0 signals to communicate with smart phones [16]. An iBeacon-enable device can notify the app on a mobile phone when the phone is approaching or leaving the location of the device. In addition to positioning, the app can also estimate the distance between the phone and the device to the precision of one to several meters. Compared with the traditional GPS that can only provide outdoor positioning to the precision of around 10 meters, iBeacon can provide very precise indoor positioning and it has already been applied in occupancy detection and service management of smart green buildings [17].

In the lab, the iBeacon sensors were deployed in the locations of the devices/systems of smart green building technologies. When the students are holding their mobile phones (installed with the app developed for the course) and approaching one of the devices/systems, the corresponding knowledge card of the device/system will be automatically pushed from the cloud to the students' mobile phones. In case of failure of iBeacon sensors to precise judge which knowledge car to push to the students' phones due to close proximity of multiple devices/systems, a QR-code was developed and posted next to each device/system in this study so that the students could obtain the corresponding knowledge card by scanning the QR code as well. Through this situated learning environment, the students could have instant understanding of not only the smart green building technologies but also their connections with the environment.

3. Methodology

3.1 Experiment design

An experiment was conducted to evaluate the benefits of the situated learning system developed in this study for the students. There are two independent variables in this study: (1) sex (male or female); (2) the students' prior knowledge levels about smart green buildings. There are two types of measurement variables: objective and subjective variables. The objective variables are the students' learning results (scores) and the time required to complete the quizzes. The subjective variables are the students' confidence in their knowledge about smart green buildings, perceived usefulness of the system, and learning interest.

3.2 Participants

There were totally 35 subjects in this study. They were 35 junior students of a department of architectural design at a university in Taiwan. With an average age of 21.4 years (standard deviation of 0.23 years), 26 of the subjects were male and nine were female. Considering the differences in their prior knowledge about smart green buildings, the subjects were given a quiz (with a total score of 10 points) about the basic concepts and technologies of smart green buildings before the experiment. Those students who scored 0–5 points were defined as the low prior knowledge group (n = 28, average score = 2.43, and Std. = 1.33); those scored 6 $\sim$ 10 points as the high prior knowledge group (n = 7, average score = 6.29, and Std. = 0.488). The average score of all the students was 3.71 points (Std. = 1.94) while that of the male students was 3.65 points (Std. = 1.92) and that of the female students was 3.89 points (Std. = 2.14) with no significant difference between them ($t = -0.308$, $p > 0.05$).

3.3 Procedure

The experiment in this study was composed of two stages. In the first stage, all the participating students were given a quiz to evaluate their prior knowledge about smart green buildings. In the second stage, the students conducted their learning about how the smart green building science and technology were used in real-life contexts in the ubiquitous situated learning lab established in this study. After their learning, they returned to the classroom and took the second quiz to find out how much they had learned about the smart green building science and technology through their situated learning. They also answered a questionnaire to measure their perceived usefulness of the system and their learning interest.

3.4 Measurement and analysis

To measure the variable of the students' prior knowledge, the students were required to take a test of 10 questions (one point for each question) and also record the time they spent in answering all the questions. In addition, before and after the use of the lab, the students were asked to answer a question using the Likert's 5-point scale to measure their confidence in their knowledge about the smart green building technologies, "Honestly, how much do you think you know about the smart green building technologies?" Their answers to this question were also recorded.

The students' perceived usefulness of the system and their learning interest were also measured respectively using two Likert's 5-point scales of ubiquitous learning (see Appendix I) revised from those developed by previous study [18]. There were six questions in the scale of perceived usefulness and seven questions in the scale of learning interest.

3.5 Data analysis

An independent t-test was first conducted to explore the influence of the subjects' sex and prior knowledge levels on each of the dependent variables. Then a paired t-test was conducted to evaluate the influence of the use of the system developed in this study on the students' confidence in their knowledge about smart green building technologies, test scores, and time spent in completing the test. Finally, a one-sample t-test was conducted to find out if the students' perceived usefulness of the system and their learning interest after their use of the system were significantly higher than the median value of 3 points (indicating "no comment") or 4 points (indicating "agreement"). A correlation analysis was conducted to explore the correlations among all the variables and find out possible connections not covered by the hypotheses of this study.

4. Results

4.1 Influence of prior knowledge

According to the independent t-test analysis results, there was only a significant difference between the students of different prior knowledge levels and their quiz scores before they used the system ($t(33) = -5.175$, $p < 0.001$). It was noteworthy that the average quiz score of the high prior knowledge group increased from 6.29 points before they used the system to 9.14 points after they used the system while the average score of the low prior knowledge group increased from 3.07 points to 6.50 points. Finally, there was no significant difference among the students with different prior knowledge levels in their quiz scores after they used the lab ($t\ (33) = -0.338$, $p > 0.05$).

These analysis results indicated (1) all the students had higher quiz scores after their use of the ubiquitous situated learning system regardless of their differences in prior knowledge levels; and (2) after their situated learning, the students with low prior knowledge could still perform as well as those with high prior knowledge in the test. It can be concluded that the ubiquitous situated learning system developed in this study can really help to improve students' learning performance regardless of their differences in prior knowledge levels.

4.2 Pre-test and post-test comparison

According to the paired sample t-test analysis results shown in Table 1, the learning activities within the situated learning system had a significantly positive influence on the students. After the learning activities, the students had a significant improvement in their knowledge confidence about smart green building technologies ($p < 0.001$) and their quiz scores ($p < 0.001$). However, there was a significant difference in the time the students spent in completing the quiz before and after they used the system. They spent 5.66 minutes more in completing the quiz after their use of the system than before their use of the system ($p < 0.001$). To conclude, the

Table 1. Comparison between Pre-test and Post-test (n = 35)

Variable	Pre-test M(SD)	Post Test M(SD)	t	Df	p
Knowledge confidence	3.11 (0.832)	3.94 (0.338)	–6.242	34	0.000**
Quiz score	3.71 (1.949)	7.03 (2.135)	–9.167	34	0.000**
Time spent	9.31 (5.357)	14.97 (5.864)	–5.246	34	0.000**

Significant Level: **p < 0.001, *p < 0.05.

situated learning system developed in this study is proven helpful for the students to increase their knowledge confidence and examination scores.

4.3 Comparison of perceived usefulness and learning interest

The average score of the subjects' perceived usefulness of the situated learning system developed in this study was 3.894 points (Std. = 0.422) and the average score of their learning interest was 3.894 points (Std. = 0.461). A one-sample t-test was conducted using the median value of 3 points (indicating "no comment") and 4 points (indicating "agreement") as the test values. According to the t-test results, both the average scores of the students' perceived usefulness and learning interest were significantly higher than 3 points ($p < 0.001$) but only the latter was significantly higher than 4 points ($p < 0.05$). When the 3.5 points was used as a test value, it was found both the average scores of the students' perceived usefulness and learning interest were significantly higher than 3.5 points ($p < 0.001$). This finding indicated that, after their use of the ubiquitous situated learning system developed in this study, the students' perceived usefulness of the system and their learning interest both increased to mid-to-high levels.

4.4 Correlations between perceived usefulness and learning interest

A Pearson correlation analysis was conducted in this study to find out the correlations among the variables. According to the analysis of the results, the students' perceived usefulness and learning interest were highly and positively correlated with each other ($r = 0.804$, $p < 0.001$). It was also found that high learning interest was positively correlated with the increase in the quiz scores after the use of the system ($r = 0.350$, $p > 0.05$) while the students with higher scores in the post test quiz spent more time in completing the quiz after the use of the system ($r = 0.437$, $p < 0.01$). The average score of the students' perceived usefulness was 3.894 (Std. = 0.422) and that of their learning interest was 3.814 (Std. = 0.461).

As indicated by the above-mentioned findings, after the use of the ubiquitous situated learning system developed in this study, those students with higher acceptance of the system (i.e. higher perceived usefulness of the system) were more likely to improve their learning results. In addition, the average scores of the students' perceived usefulness of the system and their learning interest both reached the high level, indicating that the system developed in this study can effectively promote better learning performance and interest.

Table 2. One sample t-test measures whether the measured value significantly differs from the test value

Test Value/Variable	Learning interest	Perceived usefulness
Test value = 3	t(34) = 10.462**	t(34) = 12.531**
Test value = 3.5	t(34) = 4.038**	t(34) = 5.522**
Test value = 4	t(34) = –2.386*	t(34) = –1.488

Significant Level: **p < 0.001, *p < 0.05.

5. Discussion

Generally, the ubiquitous situated learning system developed based on the STS framework in this study for the learning of smart green buildings received mid-to-high recognition from the students in terms of their perceived usefulness of the system. This finding is consistent with earlier research findings about mobile learning [19–20] or ubiquitous learning [21]. This also indicates that, with proper designs, the emerging technologies can be integrated with traditional education methods to form blended learning [22–23] and promote learners' willingness to accept this kind of new interactive learning environment.

This study also found that learners' perceived usefulness of a learning technology/system was positively correlated with their learning interest. Those students with higher acceptance of the system developed in this study were more likely to have higher learning interest as well as better learning results and confidence in their knowledge about smart green buildings. This finding is consistent with those of existing research indicating that an emerging technology can effectively increase learners' learning motivation and performance if it is accepted by them [24–26]. In addition, this study also found that, in spite of their score improvement in the quizzes, the students spent significantly more time in the second quiz after their use of the system.

It was probably because, in the first quiz before their use of the system, the students gave up on those questions to which they did not the answers directly due to their lack of relevant knowledge. Therefore, they spent less time in the first quiz. After their situated learning in the system, they improved their knowledge levels and, therefore, spent more time answering each question more carefully.

Moreover, this study also found that the ubiquitous situated learning system could help the students to effectively improve their learning results despite the differences in their prior knowledge about the science and technology of smart green buildings. This finding is different from those of existing research indicating that prior knowledge of learners would have an influence on their learning results [27]. In this study, those students with low prior knowledge could perform as well as those with high prior knowledge after the use of the system developed in this study. This finding supports those of existing research indicating that learning with multimedia assistance could significantly improve the learning results of learners with relatively low prior knowledge [28].

6. Conclusion

To conclude, the ubiquitous situated learning system developed in this study can transmit relevant knowledge about smart green buildings and IoT to learners' mobile devices so that they can learn the knowledge in the right place and right time by associating the knowledge with the devices that use the technologies. In addition, learning through the mobile devices can help students to benefit from ubiquitous learning by enabling them to link the knowledge placed in the context with the related knowledge in the real world. As a result, this kind of learning is capable of reducing the mental workload for learners. Last but not least, the interesting novelty of interactive learning through smart phones can also help to promote learning interest and better learning results.

The topic of ubiquitous learning environment has been discussed for nearly a decade. This study attempts to apply iBeacon, a new technology of wireless near-field communication (NFC), to build up a ubiquitous learning context in order to automatically provide appropriate learning information to support learning activities. However, the proposed system in this study is still in a conceptual level with room for improvement. For example, the system can already sense the in-door location of the learners and push appropriate information to learners' smart phones according to their proximity to the physical objects. However, based on the concept of incremental learning, the system should also be able to guide students' learning path by pushing information to the students in a proper sequential order so as to help them build a knowledge map step by step in their head. The learning progress in the ubiquitous learning system should be in line with the learning progress in the classroom as planned in the course syllabus. Only with this step-by-step learning will this system be able to prevent information disturbance caused by information overload for the students and allow them to focus on the current learning progress. Finally, we believe the major role of education is to promote knowledge transmission and acquisition while the information and communication technology or system only plays a supportive role to facilitate teaching and learning activities. It is hoped that the results of this study can provide references for the directions of future research to develop better learning environments by using context-aware technologies such as NFC.

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Appendix I:

Questionnaire to assess the students' learning interest:

1. I have been quite engaged in the learning process and have read carefully the knowledge cards provided by this system.
2. I find the way of learning provided by this system interesting and quite challenging.
3. I like the learning activities provided by this system.
4. I hope this learning method will be used in other courses.
5. I would like to continue using this way of learning in the future.
6. I would like to recommend this system to my classmates or friends.

Scale measuring the students' perceived usefulness of the system

1. This system can help me to concentrate on learning.
2. I can fully understand the knowledge provided by this system.
3. This system can enable me to think differently during the process of learning.
4. This system can help me to discover my personal learning problems.
5. This system can help me to correct some misconceptions.
6. This system can help me to have better understanding of the parts I have not learned well.
7. The functions of this system are helpful for my learning achievements

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